

Title: The influence of a cognitive task on the postural phase of gait initiation in Parkinson's disease: an electromyographic based analysis

Short Title: Influence of a cognitive task on gait initiation

Ângela Fernandes¹, Andreia S. P. Sousa², Nuno Rocha¹, João Manuel R. S. Tavares⁴

¹ Departamento de Terapia Ocupacional, Escola Superior da Tecnologia de Saúde do Instituto Politécnico do Porto, Faculdade de Engenharia, Universidade do Porto, PORTUGAL

² Departamento de Fisioterapia, Escola Superior da Tecnologia de Saúde do Instituto Politécnico do Porto, PORTUGAL

³ Área Científica de Terapia Ocupacional, Escola Superior da Tecnologia de Saúde do Instituto Politécnico do Porto, Laboratório de Reabilitação Psicossocial, Centro de Estudo do Movimento e da Atividade Humana, PORTUGAL

⁴ Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial, Departamento de Engenharia Mecânica, Faculdade de Engenharia, Universidade do Porto, PORTUGAL

* Corresponding author:

Prof. João Manuel R. S. Tavares

Faculdade de Engenharia da Universidade do Porto

Rua Dr. Roberto Frias, s/n, 4200-465 Porto, PORTUGAL

E-mail: tavares@fe.up.pt

Phone: +351 22 508 1487 / FAX: Phone: +351 22 508 1445

Abstract

The aim of this study was to compare postural control strategies during gait initiation in single- and dual-task conditions in individuals in early stages of Parkinson's Disease (PD).

The activation timing of tibialis anterior occurred significantly later in the individuals with PD than in the controls ($p=0.05$), and a significant interaction between the groups, conditions and limbs was found ($p=0.027$). Differences between the single- and dual-task conditions were observed for the activation timing of the tibialis anterior ($p=0.042$) and for the magnitude of soleus ($p=0.007$), with lower values for the dual-task condition. Furthermore, not all the individuals followed the previously reported pattern of soleus inhibition followed by tibialis anterior activation. The duration of the mediolateral displacement of the centre of pressure was longer in the individuals with PD than in the controls ($p=0.019$).

The anticipatory postural adjustments during gait initiation are impaired in PD and are expressed by an activation failure of tibialis anterior in both single- and dual-task conditions. Hence, it is important that during rehabilitation, intervention should concentrate on the TA.

Keywords: Dual-task; Postural control; Soleus and tibialis anterior muscles; Patterns of activity.

Introduction

Gait initiation (GI) is a transition between an upright posture and gait. In contrast, the postural phase is defined as the moment of the first vertical impulse, due to the anticipatory postural adjustments (APAs), until the maximum centre of pressure (CoP)

displacement backward and toward the first swing limb. In this phase, the CoP moves in the posterior direction, causing the displacement of the centre of gravity forwards (Caderbya et al., 2013; Yiou, Caderby, & Hussein, 2012). This movement involves the coordination of many muscles to support the load on the legs and to produce a forward movement of the body. The APAs involved in the GI have been seen as an example of muscle synergies of large muscle groups combined with a common motor function (Wang, Shapkova, Siwasakunrat, Zatsiorsky, & Latash, 2007). In young adults, the predominant pattern of muscle activity to produce movement is a bilateral inhibition of the soleus (SOL) activity, followed almost immediately by a bilateral activation of tibialis anterior (TA) activity (Crenna & Frigo, 1991; Elble, Moody, & Leffler, 1994). Individuals with PD exhibited the reported pattern of the SOL inhibition followed by the TA activation in both limbs, which is also found in individuals without pathology (Polcyn, Lipsitz, Kerrigan, & Collins, 1998). However, a decrease in the frequency of this pattern of muscle activation is expected in older individuals (Mickelborough, van der Linden, Tallis, & Ennos, 2004).

Parkinson's disease (PD) is a progressive neurodegenerative movement disorder, with decreased postural reflexes and balance (Błaszczyk & Orawiec, 2011). Individuals with PD often have difficulties to generate APAs leading to impaired forward propulsion and lateral transfer of weight when initiating gait (Hall, Brauer, Horak, & Hodges, 2013). Electromyographic (EMG) studies have demonstrated reduced SOL and TA muscle activation during APAs in GI (Gantchev, Viallet, & Aurenty, 1996; Rosin, Topka, & Dichgans, 1997). From a neurophysiological point of view, this impairment can be explained by a deregulation of neural pathways between the basal ganglia and the pedunculopontine nucleus (Schepens & Drew, 2004) and a greater use of cortical level strategies (Bloem, Grimbergen, Gert van Dijk, & Munneke, 2006; Karachi, et al., 2010;

Yarnall, Rochester, & Burn, 2011; Lima-Pardini, et al., 2012). This neuromotor dysfunction can explain the decreased displacements and velocities in the first swing limb and the increased duration of the postural phase (Gantchev et al., 1996; Hall et al., 2013; Rogers et al., 2011). On the other hand, it could be argued that bradykinesia explains the reduced APAs in PD during GI (Tokuno & Eng, 2006). In turn, the reduced CoP displacement during the postural phase of the GI contributes to the reduced length and velocity of the first step compromising the GI performance in PD (Burleigh-Jacobs, Horak, Nutt, & Obeso, 1997; Crenna et al., 2006; Halliday, Winter, Frank, Patla, & Prince, 1998). Based on the above, one would expect that the APAS dysfunction to be greater in the postural control phase of the GI in PD for more demanding cognitive tasks. In fact, in situations of dual-task, the use of cortical resources to perform motor tasks can affect or influence the performance of one or both tasks (Holmes, Jenkins, Johnson, Adams, & Spaulding, 2010; V. Kelly, A. Eusterbrock, & A. Shumway-Cook, 2012; Sethi & Raja, 2012; Woollacott & Shumway-Cook, 2002; Wu & Hallett, 2009). In comparison to controls, individuals with PD have shown an increase in cortical activity, particularly in terms of the prefrontal cortex activity, during the execution of automatic movements without activation of the striatum as would be expected. This indicates that the expected change of cortical to subcortical areas during the switch from controlled processing to automatic processing does not occur in individuals with PD (Pringsheim, Jette, Frolkis, & Steeves, 2014). Biomechanical studies of postural stability during GI and walking have clearly demonstrated that the execution of dual-task has a significant effect on postural control among individuals with PD (Nocera, Roemmich, Elrod, Altmann, & Hass, 2013; Yogev-Seligmann et al., 2010). Nevertheless, these studies have accessed the postural control strategies based on kinematic variables which hamper the reasoning about the implications of neural

impairment of PD in motor control dysfunctions during the GI. Studies of the activation timing and magnitude of TA and SOL and the muscle activation patterns can give significant insights into the comprehension of the motor control dysfunction of the GI in PD. However, there is a lack of information on the effect of dual-task on the ankle muscle activity during the GI in individuals with PD. Until now, most studies have addressed individuals in more advanced stages of the disease and, therefore, there was no information if the changes appeared in the early stages of the disease or not. Our hypothesis is that even in the early stages of the disease, individuals with PD have changes in terms of activation timing and magnitude of the ankle muscles. The confirmation of this hypothesis may be usefully for rehabilitation by establishing strategies to reduce the impact of the disease on the individuals' postural control. Based on previous studies (Nocera et al., 2013; Yogev-Seligmann et al., 2010), it can be hypothesised that the EMG activities of the SOL and TA muscles would be reduced (lower magnitude and later activation) in individuals with PD relative to controls, and that these EMG activities would also have a lower magnitude and later activation in the dual-task condition compared to the single-task condition for PD subjects, albeit without differences in terms of activation patterns. Therefore, the aim of this study was to compare the postural phase strategies during gait initiation in single- and dual-task conditions in controls and individuals with PD (Modified Hoehn and Yahr scale < 3).

Materials and Methods

Study Design and Participants

A cross-sectional study was implemented using a non-probabilistic sample of 9 individuals with PD and 10 controls, aged between 52 and 80 years old. The individuals

diagnosed with PD were patients from the Parkinson's Association, while the controls were community-dwelling volunteers matched in age, gender and limb dominance.

Subjects were excluded if they presented one of the following factors: severe cognitive impairment, screened using the Montreal Cognitive Assessment (MoCA) (Hoops et al., 2009), using a cut-off point of ≤ 26 (Duro, Simoes, Ponciano, & Santana, 2010); unable to walk independently; unable to speak; to be physical active according to the Centre for Disease Control for the American College of Sports Medicine (Thompson, 2001). It should be pointed out here that individuals who carry out physical activities improve their balance, strength, posture, gait speed, cardiovascular capacity and stamina compared to those who do not do any physical exercise (Ellis et al., 2011; Salgado, Williams, Kotian, & Salgado, 2013; Speelman et al., 2011; Yousefi, Tadibi, Khoei, & Montazeri, 2009). Also excluded were severely disabled individuals with PD (3 or more on the Modified Hoehn and Yahr scale (Hoehn & Yahr, 1967)), diagnosed as adults with any other neuromuscular disease, or those who had undergone deep brain stimulation through subthalamic surgery or were taking cholinergic medication. Controls that had been diagnosed with any neuromuscular disorder were also excluded. A trained researcher conducted the data collection based on a structured protocol. The study was approved by the Ethical Review Board of the “Escola Superior de Tecnologia da Saúde - Instituto Politécnico do Porto” in Portugal. Written informed consent, according to the Helsinki Declaration, was obtained from all participants.

Instruments

The data collected from all participants included the sociodemographic characteristics age, gender, height, weight, level of education and years of disease. Cognitive performance was assessed using the MoCA test that consists of eight fields:

visuospatial, nomination, memory, attention, language, abstraction, deferred evocation and orientation. According to this test, the performance of an individual is calculated by the addition of the scores obtained in each of the domains, and the maximum that can be reached is equal to 30 points (Hoops et al., 2009). The Modified Hoehn and Yahr Scale (Hoehn & Yahr, 1967) and part III of the Unified Parkinson's Disease Rating Scale (UPDRS-III) (Goetz et al., 2003) were also used to determine the severity of the impairment regarding the motor function of the individuals with PD who were ON medication. The UPDRS (Goetz et al., 2003), which was developed to monitor multiple aspects of PD related to disability and impairment, is made up of four parts, and is the most widely used scale for multicentre clinical trials in PD. Furthermore, this assessment tool has a satisfactory inter-rater reliability. Only the part III of the UPDRS scale was used in this study for the motor examination. The score given for each item varies from 0 to 4, from normal to severe, and the total score of part III ranged from 0 to 52. This scale is often accompanied by the Modified Hoehn and Yahr Scale (Hoehn & Yahr, 1967), which evaluates the severity of the overall dysfunction in PD. This is a 7-point scale, in which each point is a different stage of the disease (stages 1 to 5, including 1.5 and 2.5). The scale increases with the severity of dysfunction along with the stages of the disease.

The values of the vertical, anteroposterior and mediolateral components of the ground reaction force were obtained using a force platform, model FP4060-8 from Bertec Corporation (USA), according to a sampling rate of 1000 Hz (Hanke & Rogers, 1992). The platform was connected to a Bertec AM 6300 amplifier (USA) and in turn, this was connected to an analog-digital converter from Biopac Systems, Inc. (USA), and to an analog board of Qualysis Track Manager (Sweden) that can be used for stabilometric analyses. The CoP displacement was studied based on the anteroposterior and

mediolateral components registered in centimetres (cm). The bilateral (first swing and stance of the limbs) EMG activities of SOL and TA were monitored using surface EMG sensors (model emgPLUX from Plux Ltda, Portugal). The decision to assess TA and SOL was because the inhibition of the posterior muscles, i.e. medial gastrocnemius and SOL, are closely followed by the TA activity, which characterizes the start of gait (Crenna & Frigo, 1991; Elble et al., 1994). Moreover, in comparison to SOL, the medial gastrocnemius activity is clearly asymmetrical, and is less at GI in the stance limb than in the first swing limb (Burleigh, Horak, & Malouin, 1994).

The EMG signals collected with a sampling frequency of 1000 Hz were pre-amplified at the electrodes and then fed into a differential amplifier with an adjustable gain setting (25 - 500 Hz, common-mode rejection ratio (CMRR): 110 dB at 50 Hz, input impedance of 100 M Ω and gain of 1000). For the analogue to digital signal conversion and Bluetooth transmission to the computer, a wireless signal acquisition system (model bioPLUX research, from Plux Ltda (Portugal)) was used. Self-adhesive silver chloride EMG electrodes, model 505 from Dahlhausen (Germany), were used in a bipolar configuration and with a distance of 20 mm between detection surfaces (centre to centre). The skin impedance was measured with an Electrode Impedance Checker (Noraxon USA, Inc.). The EMG signals were digitized and stored for subsequent analysis in the Acqknowledge software (Biopac Systems, Inc., U.S.A).

Procedures

Skin preparation and electrode placement

The skin surfaces of the mid-belly of the muscles and the patella selected were shaved, and the dead skin cells and non-conductor elements were removed with alcohol and an abrasive pad to reduce the electrical resistance to less than 5000 Ω .

The EMG electrodes were placed on both limbs according to anatomical references: TA - 1/3 along the line from the tip of the tibia to the tip of the medial malleolus; and SOL - 2 cm distal to the lower border of the medial gastrocnemius muscle belly and 2 cm medial to the posterior midline of the leg; and the ground electrode in the centre of the patella (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000).

Data acquisition

After an explanation concerning the procedures, all individuals performed the tasks wearing shorts and standard shoes (flat shoes with rubber soles and laces). The foot alignment and the base of the support area were maintained constant over the trials. In the single-task condition, the subjects were asked to remain in the upright position for 30 seconds, looking at a point at eye level two meters away. After this interval, the subjects were instructed to walk three steps at a self-selected speed after a verbal command. If a subject asked which leg to start with, the researcher replied “whatever feels natural for you”, as the lower limb preference plays an influential role on the control of frontal plane body motion during GI (Yamada, Aoyama, Tanaka, Nagai, & Ichihashi, 2011). However, participants were asked to keep the starting leg consistent for all the trials. In the dual-task condition the subjects were required to perform the Stroop test, which consisted of naming the colour used to print the name of a different colour, while simultaneously repeating the previous procedures for a total period of 40 seconds, i.e. before and during GI. This test assesses selective attention, inhibitory capacity and concentration (Holmes et al., 2010; Romann, Dornelles, Maineri, Rieder, & Olchik, 2012). The words were placed 2 meters in front of the participants at eye level. There was no time limit to reply, thus only after the participant’s reply was the next word shown. After standing still for 30 seconds, the individuals initiated gait while

continuing to look ahead and responded to the test. The Stroop test was only performed in the dual-task condition. There was a one minute rest between each trial, and the necessary repetitions were performed in order to obtain three valid trials for each individual in each condition to reduce the within-individual variability and increase the statistical power. The data acquisition was always performed by the same trained researcher to ensure the inter-rater reliability of the technique. The single- and dual-task conditions were performed randomly in order to avoid fatigue and learning effects.

Data processing

The CoP signal was low-pass filtered with a fourth-order Butterworth filter using a zero-phase lag and a cut-off frequency of 20 Hz (Winter, 2009). The postural phase was defined as the interval between the starting of the CoP displacement (T0) in the anteroposterior and mediolateral directions until the maximum CoP displacement backward and toward the first swing limb, associated to the first deflection of the CoP signal. The CoP moves in the posterior direction, causing the displacement of the centre of gravity forwards, so the anteroposterior CoP was used. The T0 was identified as the instant when the CoP signal deviated from the mean of the baseline (obtained in the standing position) plus three standard deviations for a minimum interval of 50 ms (Shiratori & Latash, 2001). The end of the postural phase was defined as the instant associated to the first deflection of the CoP displacement (Tsukahara, Kawanishi, Hasegawa, & Sankai, 2010). The choice for the threshold used to detect the GI was due to the success that this option has had in related studies; also, the method adopted to detect the initiation of the postural phase has proved to be highly reliable in similar studies (Sousa, Silva & Santos, 2015). Thus, with these options our findings can be compared with the ones presented in the studies cited here.

The EMG signals of both limb muscles were analysed during the postural phase of the GI. The signal was filtered using a zero-lag, second-order Butterworth filter with an effective band pass of 20-450 Hz to remove mechanical artifacts from the EMG signal, and the root mean square was calculated. The magnitude of the signal was calculated for the postural phase and normalized according to the baseline values obtained during upright standing. The magnitude of the electromyographic signal was normalized by the baseline values to assess the degree of modulation of the magnitude of each muscle during the anticipatory postural adjustments in relation to upright standing (Andreia S. P. Sousa, Augusta Silva, & Rubim Santos, 2015). The activation timing of the TA muscle and deactivation timing of the SOL muscle were detected in a time window from -450 ms in relation to T0 to the end of the postural phase. Hence, these timings were defined as the time lasting for at least 50 ms when its EMG amplitude was greater than the mean of its baseline value plus 3 standard deviations or lower than the mean of its baseline value minus 3 standard deviations, measured from -500 to -450 ms, respectively. For each participant, the data of three successful trials were averaged for further analysis. The EMG signal was processed in Matlab (MathWorks, USA), Figure 1.

< Figure 1 should be inserted around here >

The Stroop test score was calculated based on the number of errors and the number of correctly named items in the colour naming test (Lezak, Howieson, & Loring, 2004) during a pre-defined time (40 seconds) for both groups. All tests were carried out with the participants taking their prescribed medications, and were therefore denoted as ON

medication, as in other studies (Conradsson, Löfgren, Ståhle, Hagströmer, & Franzén, 2012; V. E. Kelly, A. J. Eusterbrock, & A. Shumway-Cook, 2012).

Statistical Analysis

The mean and standard deviation were used for descriptive analysis. MANOVA was used to analyse the interaction between the groups (PD and control), conditions (single- and dual-task) and limbs (swing and stance). The independent variables tested were the activation timing and relative magnitude of the TA and SOL and the duration of the anteroposterior and mediolateral centre of pressure displacements in the postural phase. The Bonferroni analysis was used as a post-hoc test to determine between which of the tasks there were significant differences. The T-test for independent samples was used to compare the number of errors and the number of correctly named items between the groups. Two-tailed tests were used in all analyses and $p < 0.05$ was adopted for statistical significance. All statistical analyses were conducted using IBM SPSS Statistics 22.0 (SPSS, Inc., Chicago, IL, USA).

Results

On comparing the two groups, significant differences were observed only in the gait speed and the number of colours enumerated correctly in the Stroop test. The individuals with PD had a lower speed and enumerated less colours correctly than the controls, Table 1.

< Table 1 should be inserted around here >

The MANOVA analyses revealed a significant multivariate main effect for the single- and dual-task conditions ($p = 0.033$). Significant univariate main effects for groups were found for all tested variables, but only the activation timing of the TA was significantly later for the individuals with PD than for the controls ($p = 0.05$). Significant univariate main effects for the conditions were observed. In dual-task condition, the activation timing of the TA occurred later ($p = 0.042$) and with smaller magnitude of the SOL ($p = 0.007$), compared with single-task condition. The differences between the single- and dual-task conditions occurred in the control group in the magnitude of the TA in the first swing limb, that was significantly lower in the dual-task condition ($p = 0.042$) than in the single-task condition, Figures 2 and 3.

< Figures 2 and 3 should be inserted around here >

In terms of the postural phase duration, a significant relation was found between the conditions and groups for duration of the mediolateral CoP displacement ($p = 0.045$). Specifically, in the dual-task condition, the individuals with PD had a significantly longer duration of the mediolateral CoP displacement than the controls ($p = 0.019$). When single- and dual-task conditions were compared, no significant differences were found between the conditions in individuals with PD. However, in the controls, the duration of anteroposterior and mediolateral CoP displacements were significantly shorter in the dual-task condition than in the single-task condition ($p = 0.017$ and $p = 0.034$), Table 2.

< Table 2 should be inserted around here >

The muscle activation pattern was also analysed, Figure 4. For the first swing limb in the single-task condition, only 20% of the controls deactivated the SOL first and then activated the TA, while in the dual-task condition, 60% of the subjects followed this pattern. In the single-task condition, 56.6% of the individuals with PD followed the SOL-TA sequence, reaching 66.7% in the dual-task condition. For the stance limb in the single-task condition, 90% of the controls followed the SOL-TA sequence, while in the dual-task condition only 50% followed this sequence. In the individuals with PD in the single-task condition, 56.6% of the subjects followed the SOL-TA sequence, while in the dual-task condition the sequence was adopted by 88.9% of the subjects.

< Figure 4 should be inserted around here >

Discussion

This study revealed some differences between individuals with PD and controls in terms of postural control strategies. In the single-task condition in the swing limb and in dual-task condition in the stance limb, the TA activated significantly later in the individuals with PD compared to the controls. Also, the duration of the mediolateral CoP displacement was longer in the individuals with PD than in the controls. Differences between the single- and dual-task conditions were observed only in the control group with a later activation timing of TA, smaller magnitude of SOL and shorter duration of the postural phase in the dual-task condition. Furthermore, not all the individuals followed the previously reported pattern of soleus inhibition followed by tibialis anterior activation.

Generally, the differences between groups were more notorious in the TA muscle than in the SOL for both conditions. In fact, SOL has the same activity in swing and stance

limb during GI, but has a synergic effect with the medial gastrocnemius which has a clearly asymmetrical activity that is less during GI in the stance limb than in the first swing limb (Burleigh et al., 1994). So, an adaptation of the TA muscle is necessary, with a lower magnitude relative to the stance limb than to the swing limb. The TA muscle activated later and with lower magnitude in the individuals with PD in comparison to the controls. The TA is the main muscle to propel the body forward in the postural phase of the GI (Elble et al., 1994), but its activity is usually impaired in individuals with PD (Gantchev et al., 1996) as it tends to become weaker as the disease progresses (Crenna, Frigo, Giovannini, & Piccolo, 1990). This TA impairment can explain the longer duration of the mediolateral CoP displacement in individuals with PD compared to controls, in fact the lower backward displacement tends to increase the lateral displacement in order to release the swing limb (Carpinella et al., 2007; Nocera et al., 2013; Yiou et al., 2012) and tends to be lower in the dual-task condition relatively to the single-task condition. The dual-task condition involves the execution of two tasks simultaneously: one being the main task, with a greater focus of attention on it, and the other is the secondary task (V. E. Kelly et al., 2012; Nocera et al., 2013; Vanshika & Ravi, 2012). Biomechanical studies of postural stability have demonstrated that in the dual-task condition, subjects with Parkinson's disease (PD) exhibit impaired postural control (Nocera et al., 2013; Yogev-Seligmann et al., 2010). In addition, some authors have suggested that the dual-task condition restricts their anticipatory postural adjustments (APAs) in order to focus on the cognitive task without losing balance (Nocera et al., 2013; Yogev-Seligmann et al., 2010); however, in our study the difference found between the conditions was not significant. Contrary to the expectations, the SOL onset timing and magnitude of the individuals with PD were very similar to the ones obtained in the controls, indicating that the TA impairment is more

related to neuronal dysfunction than to a dysfunction in its antagonist (SOL). However, when comparing the single- and dual-task conditions, the individuals with PD tended to present decreased SOL deactivation in the swing limb in the dual-task in comparison to the single-task while the reverse situation occurred in the controls. In fact, only the control group presented a decreased duration of CoP displacement during the dual-task relative to the single-task. It was expected that the controls would have lower postural phase duration, since in situations of dual-task the use of cortical resources to perform motor tasks can affect or influence the performance of one or both tasks. This reduction of the duration of the postural phase in dual-task is more evident in older individuals (as in our sample) and may be associated to executive dysfunction and attention deficits (Hausdorff et al., 2006). However, adding a cognitive task does not change the SOL magnitude significantly (Nadeau, 2007; Reetz et al., 2008). Taking into account that no differences were observed in MoCA between the two groups and that the individuals with PD presented decreased performance in the Stroop test, it can be hypothesised that these individuals prioritized the motor task in detriment of the cognitive task. Unfortunately, our results do not support this hypothesis because the Stroop test was not performed in the single-task condition. Hence, future studies are required on this point. Also this finding should be considered related to the fact that GI alone is seen as a difficult task for individuals with PD (Nadeau, 2007; Reetz et al., 2008).

As to the muscle activation patterns, in a former study, Polync et al. (1998) found that most of the controls and individuals with PD exhibited the previously reported pattern of the SOL inhibition followed by the TA activation in both limbs. However, in the same study, the authors found a significant decrease of the frequency of this pattern of muscle activation in the older individuals. Other studies have suggested that the patterns of muscle activity in elderly subjects for GI are generally consistent, but noticeable

inconsistencies were found between the subjects (Mickelborough et al., 2004). In the study by Halliday et al. (Halliday et al., 1998), only three of the 10 individuals with PD showed a TA onset after the SOL inhibition. As no studies about the pattern of muscle activity in individuals with PD were found, and because the amplitudes of the TA did not increase, it was expected that the individuals with PD in this study would present a pattern of motor activation similar to the one of the “normal” subjects. However, only half of the individuals with PD studied followed the pattern of deactivation of the SOL followed by the activation of the TA. These patterns of muscular activation are similar to the aging population and may be due to the fact that the GI is not a fully automatic task, as already mentioned.

The size of the sample used in this study is in-line with other studies of this kind, such as the ones of Nocera et al. (2013), with 13 individuals with PD; Rogers et al. (2011), with 8 individuals with PD; and Schmit et al. (2005) with 6 individuals with PD. However, the sample size and consequent small statistical power is a limitation of this study; thus it should be seen as an exploratory study. Another limitation of this study was, because the GI only takes a few seconds, the starting of the Stroop task occurred before the GI. This happened because the two tasks must be performed simultaneous so that the dual-task condition could be compared to the single-task condition. Thus, the participants began by performing the Stroop test 30 seconds before the GI, and then the two tasks were performed simultaneously. However, despite the limitations always present in these studies, such as the aforementioned sample size and the potential interference of the experimental environment in GI, this study assumes particular importance because it describes the EMG analysis of the TA and SOL muscles during GI in the dual-task condition. Also, as far as the authors know, this is the first study to examine the influence of the dual-task condition in individuals with PD using EMG.

Clinical relevance

Contrary to expectations, our findings show that the SOL onset timing and magnitude of PD individuals were similar to the controls. However, there was an activation failure of the TA muscle in single- and dual-task conditions of the PD individuals compared with the controls. Therefore, knowing that the muscle synergies of the muscles studied are involved in the APAs during GI, we can conclude that an activation failure of this muscle can lead to deficits in APAs.

Acknowledgements

This research was carried out with the support and contribution of the first Author's PhD grant from the Instituto Politécnico do Porto and Escola Superior de Tecnologia da Saúde in Portugal.

Authors gratefully acknowledge the funding of Project NORTE-01-0145-FEDER-000022 - SciTech - Science and Technology for Competitive and Sustainable Industries, cofinanced by “Programa Operacional Regional do Norte” (NORTE2020), through “Fundo Europeu de Desenvolvimento Regional” (FEDER).

Conflict of interest

None declared.

References

Błaszczyk, J. W., & Orawiec, R. (2011). Assessment of postural control in patients with Parkinson's disease: sway ratio analysis. *Human Movement Science*, 30(2), 396-404. doi: 10.1016/j.humov.2010.07.017

- Burleigh-Jacobs, A., Horak, F. B., Nutt, J. G., & Obeso, J. A. (1997). Step initiation in Parkinson's disease: influence of levodopa and external sensory triggers. *Movement Disorders*, 12(2), 206-215. doi: 10.1002/mds.870120211
- Burleigh, A. L., Horak, F. B., & Malouin, F. (1994). Modification of postural responses and step initiation: evidence for goal-directed postural interactions. *Journal of neurophysiology*, 72(6), 2892-2902.
- Caderbya, T., Dalleaua, G., Leroyera, P., Bonazzia, B., Chane-Tengb, D., & Doc, M.-C. (2013). Does an Additional Load Modify the Anticipatory Postural Adjustments in Gait Initiation? . *Gait & Posture*, 37(1), 144-146. doi: 10.1016/j.gaitpost.2012.06.012
- Carpinella, I., Crenna, P., Calabrese, E., Rabuffeti, M., Mazzoleni, P., Nenni, R., & Ferrarin, M. (2007). Locomotor Function in the Early Stage of Parkinson's Disease. *IEEE Engineering in Medicine and Biology Society*, 15(4), 543-551. doi: 10.1109/TNSRE.2007.908933
- Conradsson, D., Löfgren, N., Ståhle, A., Hagströmer, M., & Franzén, E. (2012). A novel conceptual framework for balance training in Parkinson's disease-study protocol for a randomised controlled trial. *BMC Neurology*, 12, 1-11.
- Crenna, P., Carpinella, I., Rabuffetti, M., Rizzone, M., Lopiano, L., Lanotte, M., & Ferrarin, M. (2006). Impact of subthalamic nucleus stimulation on the initiation of gait in parkinson's disease. *Experimental brain research*, 172(4), 519-532. doi: 10.1007/s00221-006-0360-7
- Crenna, P., & Frigo, C. (1991). A motor programme for the initiation of forward-oriented movements in humans. *Journal of Physiology*, 437, 635-653.
- Crenna, P., Frigo, C., Giovannini, P., & Piccolo, I. (1990). *The initiation of gait in Parkinson's disease*. New York: Academic Press.

- Duro, D., Simoes, M. R., Ponciano, E., & Santana, I. (2010). Validation studies of the Portuguese experimental version of the Montreal Cognitive Assessment (MoCA): confirmatory factor analysis. *Journal of Neurology*, 257(5), 728-734. doi: 10.1007/s00415-009-5399-5
- Elble, R. J., Moody, C., & Leffler, K. (1994). The initiation of normal walking. *Movement Disorders*, 9(2), 139–146. doi: 10.1002/mds.870090203
- Ellis, T., Cavanaugh, J., Earhart, G., Ford, M., Foreman, K., & Fredman, L. (2011). Factors associated with exercise behavior in people with Parkinson's Disease. *Journal of Physical Therapy*, 91(12), 1838-1848.
- Gantchev, N., Viallet, F., & Aurenty, R. (1996). Impairment of posturokinetic coordination during initiation of forward oriented stepping movements in parkinsonian patients. *Electroencephalography and Clinical Neurophysiology*, 101(2), 110-120. doi: 10.1016/0924-980X(95)00253-H
- Goetz, C. G., Poewe, W., Rascol, O., Sampaio, C., Stebbins, G. T., Fahn, S., . . . Seidl, L. (2003). The Unified Parkinson's Disease Rating Scale (UPDRS): Status and Recommendations. *Movement Disorders*, 18(7), 738-750.
- Hall, L. M., Brauer, S. G., Horak, F., & Hodges, P. W. (2013). The effect of Parkinson's Disease and levodopa on adaptation of anticipatory postural adjustments. *Neuroscience*, 250, 483-492. doi: 10.1016/j.neuroscience.2013.07.006
- Halliday, S. E., Winter, D. A., Frank, J. S., Patla, A. E., & Prince, F. (1998). The initiation of gait in young, elderly, and Parkinson's disease subjects. *Gait and Posture*, 8(1), 8-14. doi: 10.1016/S0966-6362(98)00020-4
- Hanke, A., & Rogers, W. (1992). Reliability of ground reaction force measurements during dynamic transitions from bipedal to single-limb stance in healthy adults. *Physical Therapy*, 72(11), 810-816.

- Hausdorff, J. M., Doniger, G. M., Springer, S., Yogev, G., Simon, E. S., & Giladi, N. (2006). A common cognitive profile in elderly fallers and in patients with Parkinson's disease: the prominence of impaired executive function and attention. *Experimental Aging Research*, 32(4), 411-429. doi: 10.1080/03610730600875817
- Hermens, H., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology*, 10(5), 361-374.
- Hoehn, M. M., & Yahr, M. D. (1967). Parkinsonism: onset, progression and mortality. *Neurology*, 17(5), 427-442. doi: 10.1371/journal.pone.0069237
- Holmes, J., Jenkins, M., Johnson, A., Adams, S., & Spaulding, S. (2010). Dual-task interference: the effects of verbal cognitive tasks on upright postural stability in Parkinson's disease. *Parkinson's Disease*, 69(6), 49-52.
- Hoops, S., Nazem, S., Siderowf, A. D., Duda, J. E., Xie, S. X., Stern, M. B., & Weintraub, D. (2009). Validity of the MoCA and MMSE in the detection of MCI and dementia in Parkinson disease. *Neurology*, 73(21), 1738-1745. doi: 10.1212/WNL.0b013e3181c34b47
- Kelly, V., Eusterbrock, A., & Shumway-Cook, A. (2012). The effects of instructions on dual-task walking and cognitive task performance in people with Parkinson's Disease. *Parkinson's Disease*, 2012, 1-9. doi: 10.1155/2012/671261
- Kelly, V. E., Eusterbrock, A. J., & Shumway-Cook, A. (2012). A Review of Dual-Task Walking Deficits in People with Parkinson's Disease: Motor and Cognitive Contributions, Mechanisms, and Clinical Implications. *Parkinson's Disease*, 2012(918719), 1-14.

- Lezak, M. D., Howieson, D. B., & Loring, D. W. (2004). *Neuropsychological assessment* (4 ed.). New York: Oxford University Press, Incorporated.
- Mickelborough, J., van der Linden, M. L., Tallis, R. C., & Ennos, A. R. (2004). Muscle activity during gait initiation in normal elderly people. *Gait and Posture*, 19(1), 50-57. doi: 10.1016/S0966-6362(03)00016-X
- Nadeau, S. E. (2007). Gait apraxia: further clues to localization. *European Neurology*, 58(3), 142–145. doi: 10.1159/000104714
- Nocera, J. R., Roemmich, R., Elrod, J., Altmann, L. J. P., & Hass, C. J. (2013). Effects of Cognitive Task on Gait Initiation in Parkinson Disease: Evidence of Motor Prioritization? *Journal of Rehabilitation Research & Development*, 50(5), 699-708 doi: ORG/10.1682/JRRD.2012.06.0114
- Polcyn, A. F., Lipsitz, L. A., Kerrigan, D. C., & Collins, J. J. (1998). Age-Related Changes in the Initiation of Gait: Degradation of Central Mechanisms for Momentum Generation. *Archives of Physical Medicine Rehabilitation*, 79(12), 1582-1589. doi: 10.1016/S0003-9993(98)90425-7
- Pringsheim, T., Jette, N., Frolikis, A., & Steeves, T. L. (2014). The prevalence of Parkinson's disease: a systematic review and meta-analysis. *Movement Disorders*, 29, 1583–1590.
- Reetz, K., Siebner, H. R., Gaser, C., Hagenah, J., Buechel, C., Kasten, M., . . . Binkofski, F. (2008). Premotor gray matter volume is associated with clinical findings in idiopathic and genetically determined Parkinson's disease. *Open Neuroimaging Journal*, 27(2), 102-105. doi: 10.2174/1874440000802010102
- Rogers, M. W., Kennedy, R., Palmer, S., Pawar, M., Reising, M., Martinez, K. M., . . . MacKinnon, C. D. (2011). Postural preparation prior to stepping in patients with

- Parkinson's disease. *Journal of neurophysiology*, 106(2), 915–924. doi: 10.1152/jn.00005.2010
- Romann, A. J., Dornelles, S., Maineri, N. d. L., Rieder, C. R. d. M., & Olchik, M. R. (2012). Cognitive assessment instruments in Parkinson's disease patients undergoing deep brain stimulation. *Dementia e Neuropsychologia*, 6(1), 2-11.
- Rosin, R., Topka, H., & Dichgans, J. (1997). Gait initiation in Parkinson's disease. *Movement Disorders*, 12(5), 682– 690. doi: 10.1002/mds.870120509
- Salgado, S., Williams, N., Kotian, R., & Salgado, M. (2013). An evidence-based exercise regimen for patients with mild to moderate Parkinson's disease - Review. *Brain Sciences*, 3(1), 87-100.
- Schepens, B., & Drew, T. (2004). Independent and convergent signals from the pontomedullary reticular formation contribute to the control of posture and movement during reaching in the cat. *Journal of neurophysiology*, 92(4), 2217-2238. doi: 10.1152/jn.01189.2003
- Schmit, J. M., Riley, M. A., Dalvi, A., Sahay, A., Shear, P. K., Shockley, K. D., & Pun, R. Y. K. (2005). Deterministic Center of Pressure Patterns Characterize Postural Instability in Parkinson's Disease. *Experimental brain research*, 168(3), 357-367. doi: 10.1007/s00221-005-0094-y
- Sethi, V., & Raja, R. (2012). Effects of Dual task training on balance and activities of Daily Livings (ADLs) in patients with Parkinsonism. *International Journal of Biological & Medical Research*, 3(3), 1359-1364.
- Shiratori, T., & Latash, M. L. (2001). Anticipatory postural adjustments during load catching by standing subjects. *Clinical neurophysiology*, 112(7), 1250-1265. doi: 10.1016/S1388-2457(01)00553-3

- Sousa, A. S. P., Silva, A., & Santos, R. (2015). Ankle anticipatory postural adjustments during gait initiation in healthy and post-stroke subjects. *Clinical Biomechanics*, 30(9), 960-965. doi: <http://dx.doi.org/10.1016/j.clinbiomech.2015.07.002>
- Sousa, A. S. P., Silva, A., & Santos, R. (2015). Reliability of Two Methods for Identifying the Postural Phase of Gait Initiation in Healthy and Poststroke Subjects. *Journal of Applied Biomechanics*, 31, 349-356. doi: 10.1123/jab.2014-0222
- Speelman, A., Van de Warrenburg, B., Van Nimwegen, M., Petzinger, G., Munneke, M., & Bloem, B. N. R. N., 7. (2011). How Might Physical Activity Benefit Patients with Parkinson Disease? *Nature Reviews Neurology*, 7(9), 528-534.
- Thompson, W. (2001). *ACSM's Guidelines for Exercise Testing and Prescription* (8 ed.). Lippincott: Williams & Williams.
- Tokuno, C. D., & Eng, J. J. (2006). Gait initiation is dependent on the function of the paretic trailing limb in individuals with stroke. *Gait & Posture*, 24(4), 424-428. doi: <http://dx.doi.org/10.1016/j.gaitpost.2005.09.012>
- Tsukahara, A., Kawanishi, R., Hasegawa, Y., & Sankai, Y. (2010). Sit-to-Stand and Stand-to-Sit Transfer Support for Complete Paraplegic Patients with Robot Suit HAL. *Advanced Robotics*, 24(11), 1615–1638. doi: 10.1163/016918610X512622
- Vanshika, S., & Ravi, R. (2012). Effects of Dual task training on balance and activities of Daily Livings (ADLs) in patients with Parkinsonism. *International Journal of Biological & Medical Research*, 3(1), 1359-1364.
- Wang, Y., Shapkova, E. Y., Siwasakunrat, S., Zatsiorsky, V. M., & Latash, M. L. (2007). Stepping from a narrow support. *Journal of Electromyography & Kinesiology*, 17(4), 462–472. doi: 10.1016/j.jelekin.2006.04.012

- Winter, D. (2009). *Biomechanics and Motor Control Of Human Movement* (4th ed.): Wiley.
- Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: a review of an emerging area of research. *Gait Posture*, 16(1), 1–14. doi: 10.1016/S0966-6362(01)00156-4
- Wu, T., & Hallett, M. (2009). Dual Task Interference in Parkinson's Disease. *US Neurology*.
- Yamada, M., Aoyama, T., Tanaka, B., Nagai, K., & Ichihashi, N. (2011). Seated stepping exercise in a dual-task condition improves ambulatory function with a secondary task: a randomized controlled trial. *Aging clinical and experimental research*, 23(5-6), 386-392.
- Yiou, E., Caderby, T., & Hussein, T. (2012). Adaptability of Anticipatory Postural Adjustments Associated With Voluntary Movement *World Journal of Orthopedics*, 3(6), 75-86. doi: 10.5312/wjo.v3.i6.75.
- Yogev-Seligmann, G., Rotem-Galili, Y., Mirelman, A., Dickstein, R., Giladi, N., & Hausdorff, J. (2010). How Does Explicit Prioritization Alter Walking During Dual-Task Performance? Effects of Age and Sex on Gait Speed and Variability. *Physical Therapy*, 9(2), 1-10. doi: 10.2522/ptj.20090043
- Yousefi, B., Tadibi, V., Khoei, A. F., & Montazeri, A. (2009). Exercise therapy, quality of life, and activities of daily living in patients with Parkinson disease: a small scale quasi-randomised trial. *Trials*, 11, 10-67.

FIGURE CAPTIONS

Figure 1 – Representation of the activation timing and the relative magnitude of the activation of the TA and SOL muscles during gait initiation in an individual with PD and a control in terms of the electromyography data.

Figure 2 – Mean and standard deviation values for the activation timing of the TA and SOL muscles, in first swing and stance limbs, and comparison between single- and dual-task conditions as well as between the individuals with PD and the controls.

Figure 3 – Mean and standard deviation values for the relative magnitude of the TA and SOL muscles, in first swing and stance limbs, and comparison between single- and dual-task conditions as well as between the individuals with PD and the controls.

Figure 4 – Percentage of individuals that followed the motor activation pattern: deactivation of the SOL followed by activation of the TA in the first swing and stance limbs in the controls and individuals with PD.

TABLE CAPTIONS

Table 1 – Comparison of the sociodemographic variables, gait speed, Montreal Cognitive Assessment (MoCA) score, number of colours named and number of errors in the Stroop test and the part III of the Unified Parkinson's Disease Rating Scale (UPDRS-III). (Significant values ($p < 0.05$) in bold.)

Table 2 – Mean and standard deviation values for the duration of the anteroposterior and mediolateral CoP displacements and comparison between single- and dual-task conditions as well as between the individuals with PD and the controls.

FIGURES

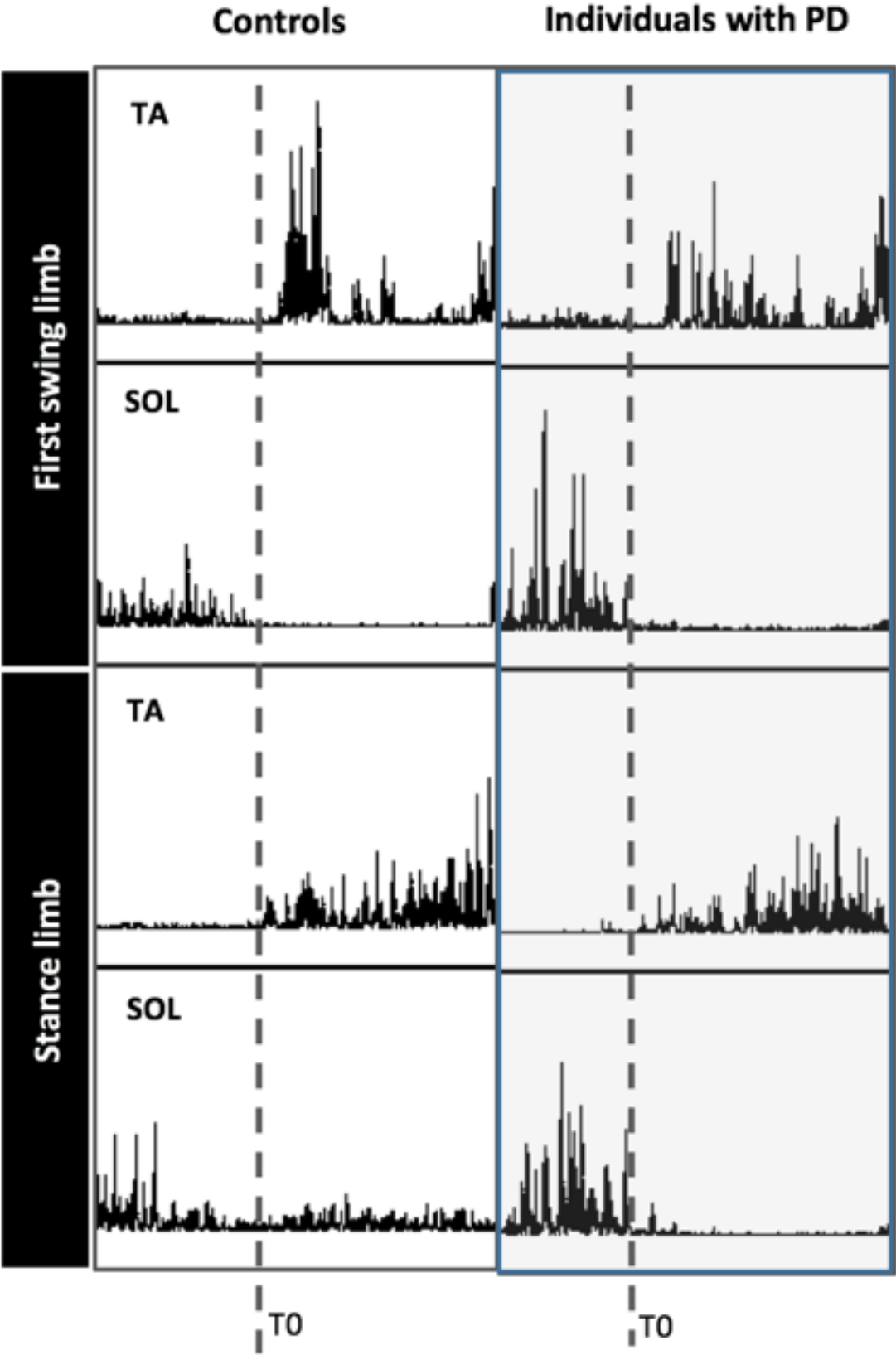


Figure 1

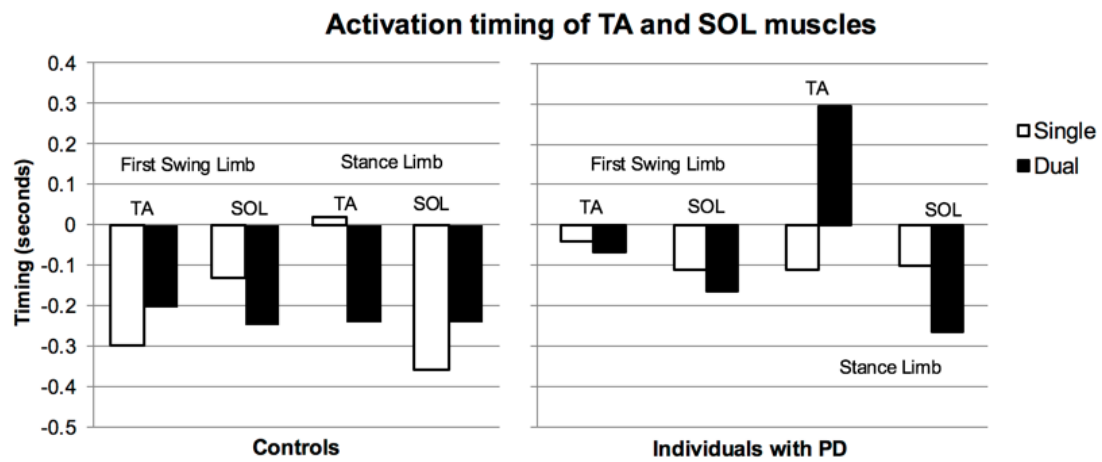


Figure 2

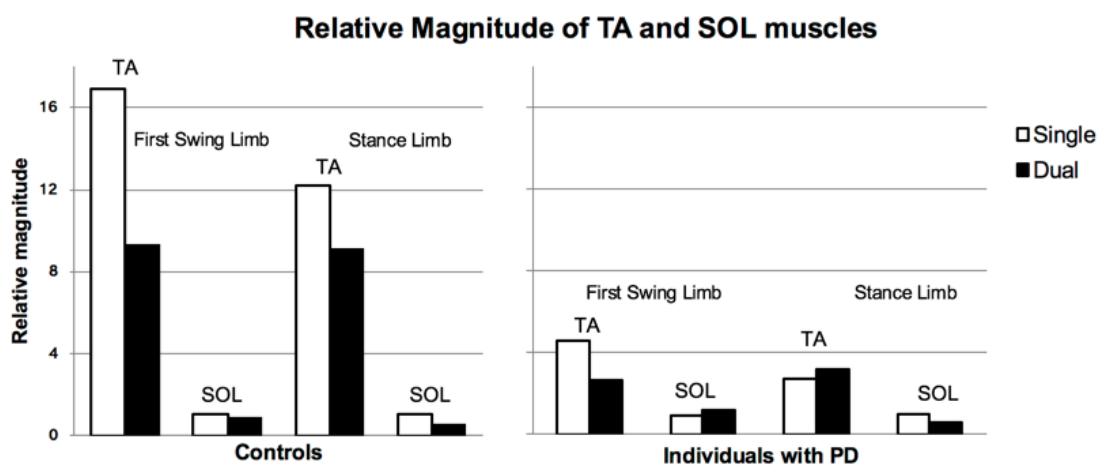


Figure 3

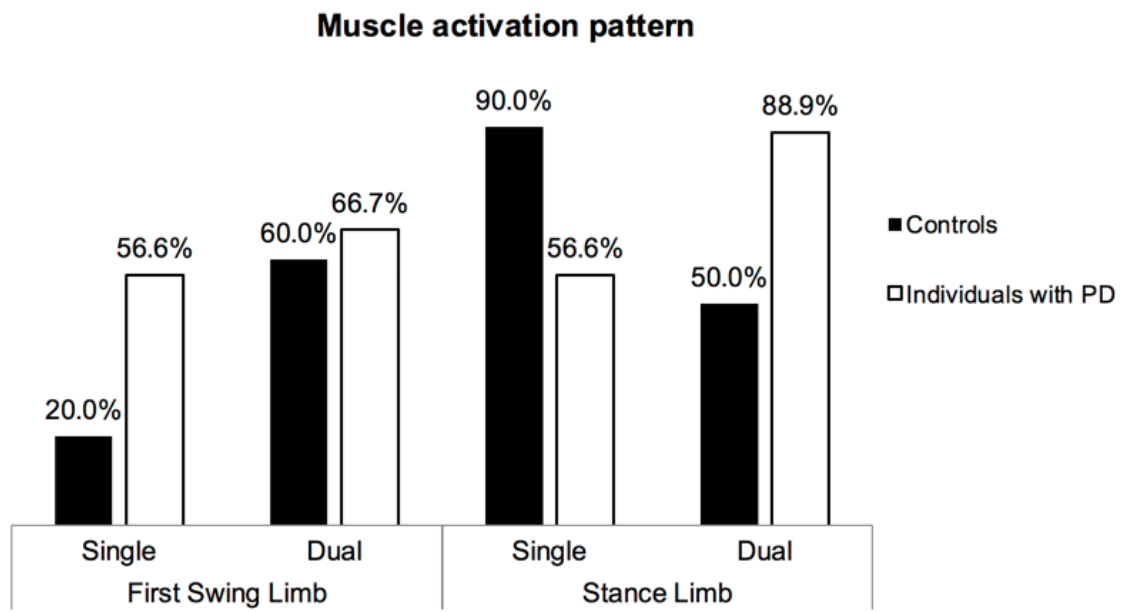


Figure 4

TABLES

Table 1

	Controls (n=10)	Individual with PD (n=9)	p-value
	M (SD)	M (SD)	
Age [years]	63.70 (2.42)	66.00 (2.74)	0.252
Male, n (%)	5 (50)	6 (66.7)	0.463 ^a
Education [years]	8.20 (1.43)	7.67 (1.69)	0.696
Weight [Kg]	72.90 (3.14)	69.33 (4.20)	1.000
Height [m]	1.64 (0.03)	1.65 (0.03)	0.931
Gait Speed	1.11 (0.13)	0.96 (0.11)	0.030
MoCA test score	26.50 (1.58)	24.78 (5.57)	0.095
Stroop test: N° colours named	24.30 (5.19)	18.17 (5.21)	0.035
Stroop test: N° Errors	0.63 (0.49)	1.18 (1.45)	0.968
UPDRS-III		13.78 (3.53)	

^a chi-square test

M – Mean

SD – Standard Deviation

Table 2

Postural Phase Duration	Condition	Controls			Individuals with PD			p-value
		n	M (SD)	p-value	n	M (SD)	p-value	
Anteroposterior CoP displacement [seconds]	Single	10	0.312 (0.112)	0.017	9	0.264 (0.204)	ns	ns
	Dual	10	0.190 (0.076)		8	0.188 (0.075)	ns	ns
Mediolateral CoP displacement [seconds]	Single	10	0.225 (0.411)	0.034	9	0.249 (0.052)	ns	ns
	Dual	10	0.170 (0.075)		9	0.274 (0.099)	ns	0.019

M – Mean

SD – Standard Deviation

ns – not-significant